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Effects of Free-Hanging Horizontal Sound Absorbers on the Cooling Performance of Thermally Activated Building Systems

L. Marcos Domínguez, Nils Rage, Ongun B. Kazanci, Bjarne W. Olesen

***Abstract*—**Thermally Activated Building Systems (TABS) have proven to be an energy-efficient solution to provide buildings with an optimal indoor thermal environment. This solution uses the structure of the building to store heat, reduce the peak loads, and decrease the primary energy demand. TABS require the heated or cooled surfaces to be as exposed as possible to the indoor space, but exposing the bare concrete surfaces has a diminishing effect on the acoustic qualities of the spaces in a building. Acoustic solutions capable of providing optimal acoustic comfort and allowing the heat exchange between the TABS and the room are desirable. In this study, the effects of free-hanging units on the cooling performance of TABS and the occupants' thermal comfort was measured in a full-scale TABS laboratory. Investigations demonstrate that the use of free-hanging sound absorbers are compatible with the performance of TABS and the occupant's thermal comfort, but an appropriate acoustic design is needed to find the most suitable solution for each case. The results show a reduction of 11% of the cooling performance of the TABS when 43% of the ceiling area is covered with free-hanging horizontal sound absorbers, of 23% for 60% ceiling coverage ratio and of 36% for 80% coverage. Measurements in actual buildings showed an increase of the room operative temperature of 0.3 K when 50% of the ceiling surface is covered with horizontal panels and of 0.8 to 1 K for a 70% coverage ratio. According to numerical simulations using a new TRNSYS Type, the use of comfort ventilation has a considerable influence on the thermal conditions in the room; if the ventilation is removed, then the operative temperature increases by 1.8 K for a 60%-covered ceiling.

***Keywords*—**Acoustic comfort, concrete core activation, full-scale measurements, thermally activated building systems, TRNSYS.

I. Introduction

A building's function is to provide a safe and healthy enclosure for people's activities, to protect them from the outdoor environment, and to provide optimal levels of comfort. On the other hand, buildings need energy to provide the desired indoor environmental conditions. According to the European Environment Agency, buildings are responsible for about 40% of the total energy use in the European Union [1]. Introducing energy savings involves higher costs when a building has already been constructed. For this reason, the integration of energy savings and the use of sustainable energy resources should be a priority from the early stages of the building design. Low temperature heating and high temperature cooling systems (water-based radiant heating and cooling systems in this context) have proven to be an energy efficient solution for conditioning buildings [2]. In this group, TABS are an example of radiant heating and cooling systems. TABS' main principle is to use the thermal mass of the building in order to store heat and activate the building thermal mass by embedding water-carrying pipes in the building structure. The thermal indoor environment is controlled by emitting or removing heat from the indoor space by heated or cooled TABS surfaces, and by adding or extracting heat from the TABS structure by water circulation. On the other hand, TABS require large hard surfaces to be exposed, which could have a negative impact on the acoustic quality of indoor spaces. In the case of office spaces, a productivity reduction of 67% was reported in employees working in noisy spaces [3]. Free-hanging ceiling absorbers can be a solution for addressing acoustic concerns; however, they will affect the cooling performance of TABS.

This study quantifies the effects free-hanging horizontal ceiling absorbers on the cooling performance of TABS and the implications that this has on the thermal comfort of the occupants. In order to study the effects, experiments in a full-scale test facility were performed. Operative temperature measurements were compared with measurements in actual buildings obtained from literature [4]. A sensitivity analysis with different operating conditions was performed in TRNSYS with a new TRNSYS Type (Ecophon Acoustic Elements).

II. Methods

A. Acoustic Panels and Layout

Horizontal sound absorber units (Fig. 1) that were identified to be compatible with the performance of TABS were selected [5], i.e. they allow the heat exchange between the TABS and the room through convection and radiation (at least partially).

The sound absorbers are made of high density glass wool with dimensions 1160 x 1000 mm and a thickness of 40 mm. The panels were installed at a distance of 300 mm from the soffit aiming for an even distribution along the ceiling area.

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Table I shows the scenarios studied. Fig. 2 shows the installation of the free-hanging units in the test facility.

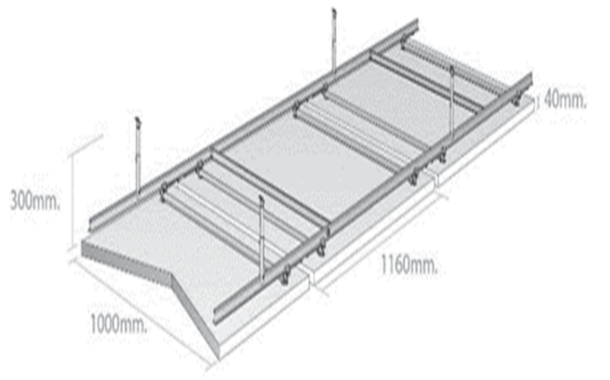

Fig. 1 Free-hanging horizontal sound absorbers dimensions [6]

TABLE I
SUMMARY OF SCENARIOS

Scenario	Coverage ratio	Number of horizontal panels
1	0%	0
2	43%	8
3	60%	11
4	80%	15

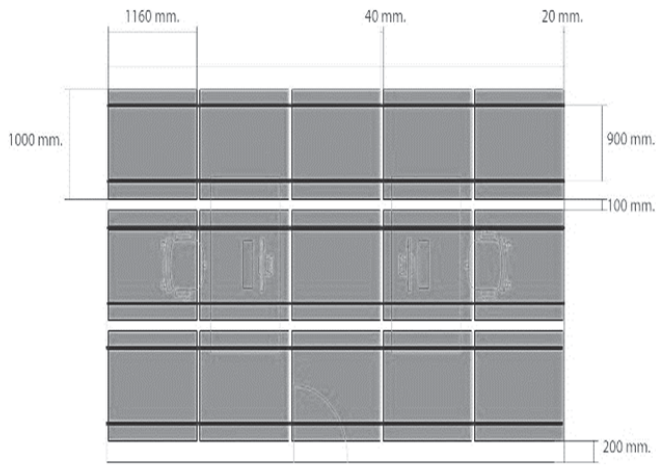

Fig. 2 Grid dimensions in the full-scale facility

B. Test Facility

Experiments were carried out in a test facility located at the Technical University of Denmark that resembles a room in a building with TABS. The facility consists of a 21.6 m2 room with a ceiling height of 3.6 m. The floor and ceiling consist of thermo-active concrete decks to attain realistic conditions of a multi-storey building with TABS. The room and the decks are surrounded by a thermal guard, whose temperature is controlled to ensure an equal temperature to that inside the room and hence avoid thermal losses or gains. Fig. 3 shows the details of the test facility.

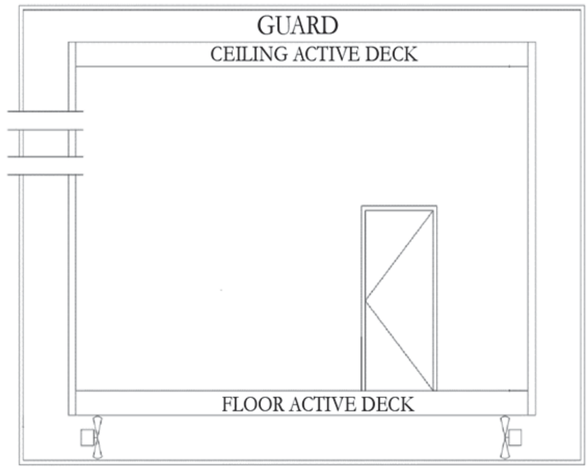

Fig. 3 Descriptive geometry of the test facility (longitudinal section)

TABLE II
SUMMARY OF SCENARIOS

Constant condition	Value
Total heat loads, W/m^2	35
Occupants, W	2 x 65
Lights, W	4 x 50
Computer, W	2 x 120
Solar gains (heating mat), W	1x 175
Ventilation supply temperature, °C	20
Ventilation rate, ACH	1.35
Water supply temperature decks, °C	15
Water flow rate (floor/ceiling), kg/h	293/283

The room has a ventilation system that is capable of providing airflow at a defined flow rate and temperature. In order to simulate a two-person office room, heat loads were represented by means of two thermal manikins, two computers with monitors, four light bulbs, and a heating mat on a wall representing the solar heat gains from a window on a summer day. Experimental conditions are summarized in Table II.

The thermal indoor environment in the room was assessed by means of air and operative temperature (using thermocouples) as shown in Fig. 4. Sensors to assess the thermal comfort of the occupants were mounted at different levels according to the recommendation in ISO EN 7726 [7], which were 0.1 m, 0.6 m, 1.1 m, and 1.7 m. Further information about the sensors' accuracy, and measuring range can be found in [8].

Each TABS deck consisted of three prefabricated concrete decks covering the entire area of the ceiling and floor. Fig. 5 shows the dimensions of the deck. PEX pipes of 20 mm outer diameter and 2 mm thickness are embedded in the concrete mass. The flow and the supply and return temperature were measured with a Kamstrup Multical 302.

Measurements were performed under steady-state conditions, and data were obtained once the steady-state conditions were reached.

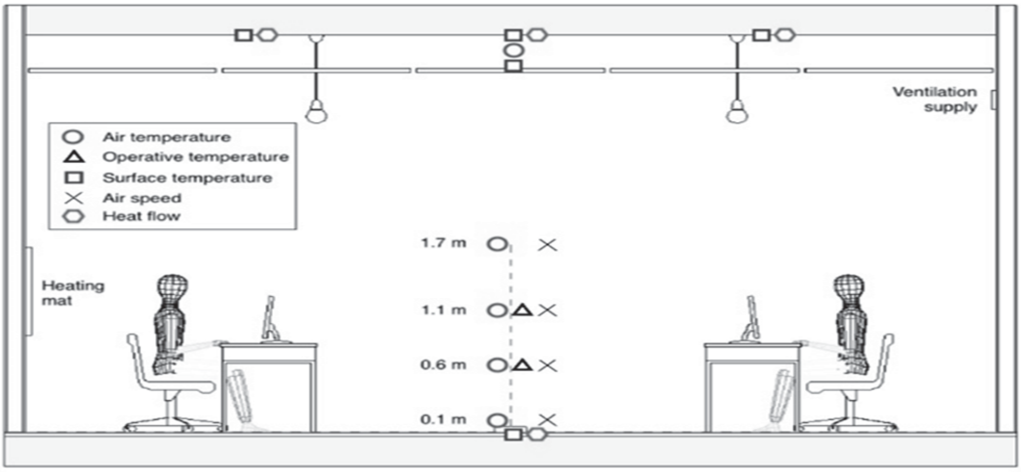

Fig. 4 Position of the measurements and heat loads in the room

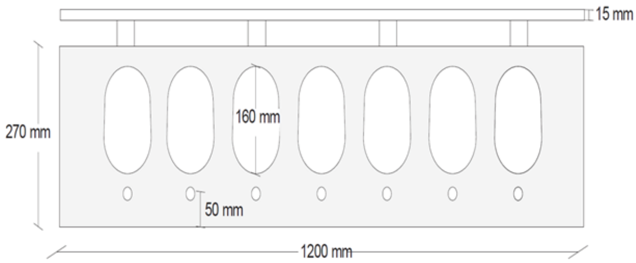

Fig. 5 Descriptive geometry of one prefabricated concrete deck

C. Data Analysis

The focus of this study was to evaluate the effects of different scenarios with sound absorbers on the cooling performance of the upper level decks (ceiling cooling). Assuming steady-state conditions, the energy balance in the decks is found from (1):

$$q_{pipe} = q_{up} + q_{down} + q_{guard} \qquad (1)$$

where q_{pipe} is the heat flow in the pipe [W], q_{up} is the heat flow through the ceiling surface [W], q_{down} is the heat flow through the floor covering [W], and q_{guard} is the heat flow between the sides of the deck and the guard [W]. This latter can be neglected since the perimeter of the slab is insulated [9]. q_{up} was used to calculate the TABS cooling performance. Fig. 6 shows the heat flows in the decks.

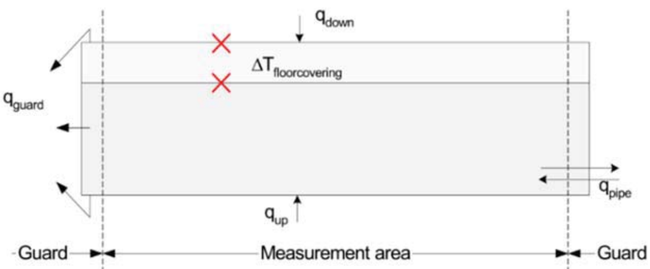

Fig. 6 Heat flows in the decks [9]

The heat flow between the pipes and the concrete decks (q_{pipe}) can be calculated from the measured water flow rate and the temperature difference between the supply and return water flows. q_{pipe} can be found from (2):

$$q_{pipe} = \dot{m} \cdot c_p \cdot (T_{supply} - T_{return}) \qquad (2)$$

where ṁ is the mass flow rate of the fluid in the pipes [kg/s], c_p is the specific heat capacity of the fluid in the pipes [kJ/(kg.K)], T_{supply} is the supply temperature of the water [°C], T_{return} is the return temperature of the water [°C]. The heat flow across the floor covering (q_{down}) can be calculated from (3):

$$q_{down} = \frac{1}{R_{floor\ covering}} \cdot \Delta T_{floor\ covering} \qquad (3)$$

where $R_{floor\ covering}$ is the resistance of the floor covering [m^2K/W], and $\Delta T_{floor\ covering}$ is the temperature difference [°C] between the upper and lower surfaces of the floor covering.

However, when assessing the cooling performance of the TABS using the cooling capacity of the active surface of the deck, it should be noted that this parameter is influenced by the temperature of the room and this is expected to vary depending on which scenario is tested. Based on these observations, Weitzmann [9] has proven that one parameter remained almost constant for each scenario, i.e. cooling capacity coefficient (U_{cc}). The cooling capacity coefficient of the ceiling (U_{cc}) is defined as [9]:

$$U_{cc} = \frac{q_{up}}{A_{deck} \cdot (T_{room} - T_{fluid})} \qquad (4)$$

where A_{deck} is the area of the deck [m^2], T_{room} is the operative temperature [°C], and T_{fluid} is the average temperature of the water in the decks [°C].

Further details of the testing facility and the experimental conditions can be found in [8]-[10]. Simulations in TRNSYS were performed with the same operating conditions as the ones found in the test facility. Details of the model can be found in [10]. Details of the measurements in an actual building with TABS can be found in [4].

III. Results and Discussion

A. Measurements

Fig. 7 shows the cooling capacity coefficient and cooling performance reduction as a function of the ceiling coverage ratio.

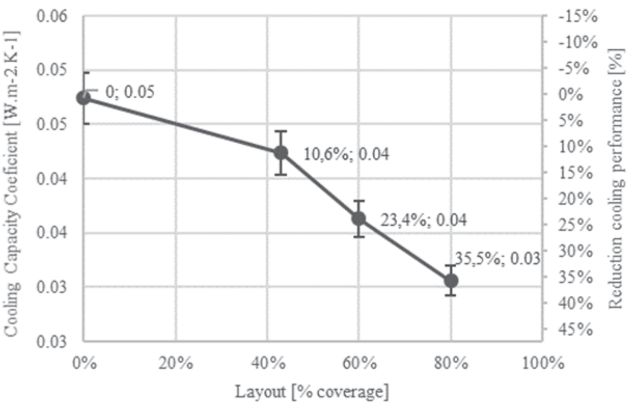

Fig. 7 Cooling capacity coefficient and reduction of cooling performance as a function of the ceiling surface area covered with horizontal panels

Fig. 7 shows that the cooling performance of the TABS decreases when the ceiling surface coverage increases. The heat exchange between the room and the TABS is hindered when the ceiling is covered with free-hanging horizontal sound absorbers. This reduction, compared to the bare-ceiling, accounts for 10.6% with 43% coverage, 23.4% with 60% coverage, and 35.5% for 80% of the ceiling surface covered with panels.

Fig. 8 shows operative temperatures measured in the test facility compared with operative temperatures measured in an actual building with TABS [4].

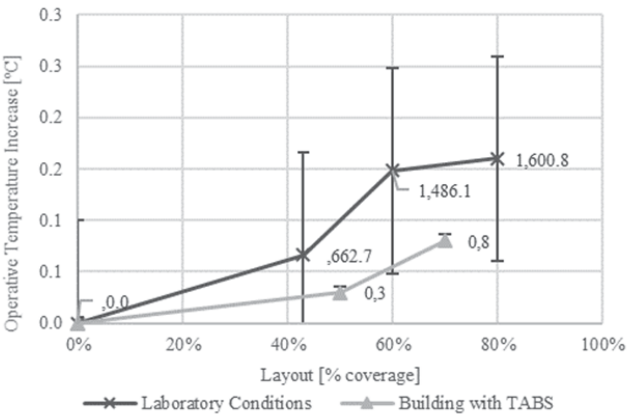

Fig. 8 Cooling capacity coefficient and reduction of cooling performance as a function of the ceiling surface area covered with horizontal panels

As a result of the reduction in cooling performance, the operative temperature in the occupied space increases. In laboratory conditions, this increase was 1.5 and 1.6 K for 60% and 80% coverage, respectively. However, measurements in a building with TABS show an increase of 0.3 and 0.8 K for 50% and 70% coverage, respectively [4].

Although the conditions were different between the experiments and the field measurements, it may be seen that the influence of the free-hanging units on the operative temperature is lower in a real building than the one measured in laboratory conditions. Real conditions in buildings could lead to a lower degradation of the thermal indoor environment due to the presence of the sound absorbers.

Fig. 9 shows the air temperatures at measured heights in the vertical plane in laboratory conditions for different ceiling coverage ratios. The horizontal dashed line shows the level of the sound absorbers, and the horizontal solid line shows the level of the soffit.

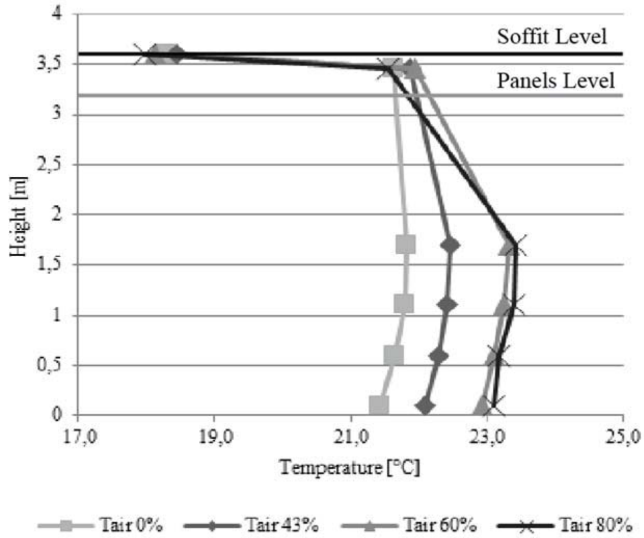

Fig. 9 Air temperature distribution in the vertical plane in laboratory conditions

Fig. 9 shows that the temperature difference between the plenum space and 0.6 m above the floor level was 0.6 K for 43% coverage, 1.4 K for 60% coverage, and 1.8 K for 80% coverage, whereas it was 0.2 K for the bare-ceiling at the same measuring points. This shows that the horizontal panels are preventing the cooled air from mixing with the rest of the air in the room; this effect becomes more pronounced with a higher ceiling coverage ratio. The masking effect of the panels, not only prevents stagnated cold air from mixing with the room air, but also degrades the cooling performance of the TABS.

B. Sensitivity Analysis

Simulations in TRNSYS 17.0 with the Type Ecophon Acoustic Elements were performed to complete a sensitivity analysis. The varied parameters were:

- The absence of ventilation in the room: ACH=0.
- Smaller internal heat gains: The simulated solar gain has been removed from the model, leading to an internal heat gain of 27 W/m^2.
- Increased TABS supply water temperature from 15 °C to 17 °C and 19 °C.

- Higher and lower air supply temperature to the room: 22 °C and 18 °C.

Fig. 10 shows the results of the sensitivity analysis. The parameter investigated is the operative temperature increase between an uncovered and a 60%-covered deck, which is measured in a reference location in the room.

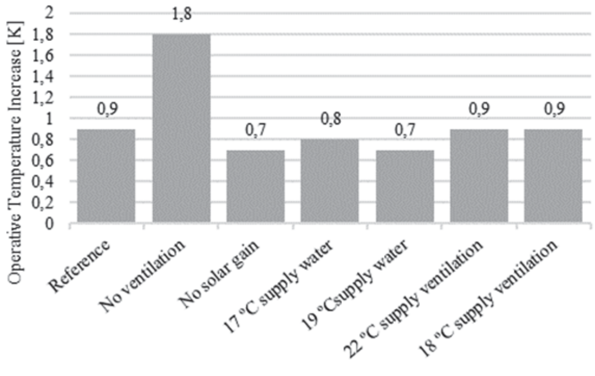

Fig. 10 Operative temperature increase between a bare TABS ceiling and a 60%-covered ceiling for different cases [10]

According to the TRNSYS simulations, the increase in operative temperature when covering 60% of the ceiling surface is similar for all the cases when ventilation is supplied to the room. The effect of the panels is much more contrasted as soon as the fresh air supply is removed. A temperature increase of 1.8 K has been observed. Hence, the effect of the panels will be much more pronounced in a case with no ventilation in the building.

IV. Conclusion

The effects of horizontal sound absorbers on TABS cooling performance in a test facility were investigated in this study. The diminishing effect on the cooling performance of TABS due to the presence of horizontal panels can be quantified as follows; 11% reduction when 43% of the surface of the ceiling is covered, 23% reduction for a coverage ratio of 60%, and 36% reduction for 80% coverage ratio. As a consequence of the reduction in cooling performance, the operative temperature in the occupied space increases. This increase was of 0.7, 1.5 and 1.6 K for 43%, 60% and 80% coverage, respectively. The actual effects could be different in real buildings. Measurements in an actual building show an increase in operative temperature of 0.3 and 0.8 K for 50% and 70% coverage, respectively [4].

The sensitivity analysis showed that the ventilation plays a crucial role in removing heat from the room, and plays a crucial role in keeping the room temperatures acceptable. Cold air stagnation in the plenum has been identified as the major problem for the convective heat exchange between the TABS and the room. A coverage ratio of 60% can be considered optimal from the acoustic [5] and thermal point of view, though these panels need to be combined with wall-mounted acoustic units to achieve an optimal sound absorption in the full spectrum of frequencies. Future investigations could focus on alternative ventilation strategies in combination with free-hanging elements and TABS.

Acknowledgment

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References

[1] EEA. (2001). End-user GHG emissions from energy. Reallocation of emissions from energy industries to end users 2005-2009. European Environment Agency Report No 19/2001.
[2] Babiak, J., Olesen, B. W., & Petras, D. (2013). Low Temperature Heating and High Temperature Cooling, REHVA Guidebook, vol. 7, 2009.
[3] S.P. Banbury (1998), D.C. Berry, “Disruption of Office-Related Tasks by Speech and Office Noise”. British Journal of Psychology, 89 (3), 499-517.
[4] Muet, Y. Le, Peperkamp, H., & Machner, R. (2013). Combining thermally activated cooling technology (TABS) and high acoustic demand: Acoustic and thermal results from field measurements, Inter-Noise, International Congress, and Exposition on Noise Control Engineering, Innsbruck, 15-18 September 2013.
[5] Ecophon. (2015). Knowledge guide. Sound absorption – free-hanging units vs. full ceiling.
[6] Ecophon. (2015). Ecophon Master TM Matrix Technical datasheet.
[7] ISO 7726:2012, Ergonomics of the thermal environment. Instruments for measuring physical quantities. ISO 2012
[8] Domínguez, L. M. (2016). Influence of Acoustic Ceiling Units on the Cooling Performance of Thermo-Active Building Systems (TABS), (February).
[9] Weitzmann, P. (2004). Modelling building integrated heating and cooling systems. PhD dissertation, Dept. of Civil Engineering, Technical University of Denmark, Lyngby.
[10] Rage, N. (2015). Experimental and theoretical study of the influence of acoustic panels on the heat exchange between Thermo-Active Building Systems (TABS), the occupants and the room, (July).